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A CODE TRANSFORMATION TASK THAT PROVIDES PERFORMANCE MEASURES OF NONVERBAL MEDIATION (COTRAN)

by Earl A. Alluisi and Glynn D. Coates

Prepared by
UNIVERSITY OF LOUISVILLE
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Foreword

This report was prepared by Dr. Earl A. Alluisi, Professor of Psychology, and Dr. Glynn D. Coates, Research Associate, both of the University of Louisville, Louisville, Kentucky, 40208. The research program under which this work was completed is supported by the National Aeronautics and Space Administration under Research Grant No. SC/NGR-18-002-008, "Performance Measurement of Intellectual Functioning," monitored by the Human Performance Branch, Biotechnology Division, Life Sciences, NASA Ames Research Center, Moffett Field, California.

Distribution of this report is provided in the interest of information exchange. Responsibility for the contents resides in the authors or organization that prepared it.

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Abstract

A code-transformation (COTRAN) task has been designed to follow the model of the problem-solving paradigm. The task is intended to provide performance measures of that part of intellectual functioning which is typically called "nonverbal mediation."

The results of two experiments are reported. In the first experiment, 90 subjects worked at the COTRAN task under one of a set of six conditions which represented the factorial combination of two memory-aid and three transformation-complexity conditions. Seventy-two measures of COTRAN performance were factor analyzed, and five COTRAN factors were identified. Nine measures were selected to represent the five factors, and with these measures it was found that performance with two memory aids was better than with one. The factorial structure was the same under the two conditions.

In the second experiment, 84 subjects each completed 18 COTRAN problems as well as a set of paper-and-pencil tests of intellectual abilities and personality. A factor analysis of the 75 measures used resulted in the identification of five COTRAN factors (the same as in the first experiment) and three additional factors--one for verbal intelligence, and two for personality characteristics.

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Introduction

If one had the responsibility of monitoring the performance and physiological condition of a vehicle operator such as a pilot or an astronaut, what behavioral information would be necessary in order to represent his current, momentary level of performance? What biological or physiological information would be necessary? How would the two kinds of information be collated to provide a valid assessment of the current state of his performance and physiology? Also, if part of the responsibility was the ordering of a "return to base" that could be accomplished only in an hour or two after the order, how could the information be used to predict the operator's performance during that future hour or two?

The fact that there is no set of correct answers to these questions demonstrates that little is known concerning the assessment of human performance in operational systems. Yet, this problem of performance assessment is probably the most important, the most difficult, and to some extent the least-studied problem in human factors engineering today. Most of the applicable research is concerned either with system-performance measures based in part on operator performances in a specific system (e.g., Grodsky, 1966), or with more general aspects of performance in simpler, non-system-like, laboratory settings (e.g., Parker, 1966). In following either of these approaches, questions concerning the general assessment of operator performance are left largely unanswered.

Direct attacks on the more general question can be (and have been) made, however, through an approach that attempts to measure the performance of operators on a standard battery of tasks, in a multiple-task performance setting, where the tasks themselves represent the functions that man can be expected to perform in operating any vehicle system (Alluisi, 1966). The research previously completed in this area forms part of the background for the present research, while another part of the background is formed by relatively recent studies of man's problem-solving behavior. Brief summaries of these two areas will be presented in this introduction prior to a description of the task developed and the methodology employed in the experimentation that followed its development.

The intent of the present research is to extend this background in order to provide a task for the performance measurement of certain aspects of intellectual functioning--a task that could be used alone, or as part of the battery of tasks already developed as a "synthetic" work situation, or in any subsequently developed multiple-task performance battery.

Background in Performance Measurement

The Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, began a program of research on crew performance in 1956; much of the research was conducted under contract at the Human Factors Research Laboratory of the Lockheed-Georgia Company, Marietta, Georgia. The plan was to conduct research on crew performance applicable to advanced systems of a general class "ten years in the future." No specific system was to be simulated directly, but it was hoped that a generalized system (in terms of the functions required of the operators) could be devised and that the data obtained with use of this would be applicable to a wide range of specific systems that employed the same functions.

It was decided at an early date that major emphasis would be placed on operator performance of the functional aspects of mission-related tasks, and a group of tasks was assembled.

A crew compartment was designed and constructed, as were also the performance panels, the programming and scoring apparatus, and the experimenters' control consoles, and an initial experiment was conducted to answer questions concerning certain technical aspects of the battery such as reliability and intertask correlations (see Adams, Levine, & Chiles, 1959; Adams, 1958).

Among the variables investigated in later studies were the following: (1) the work-rest cycle (8-hours on duty and 8-hours off, 6-6, 4-4, and 2-2), (2) the work-rest ratio (1:1, 2:1, and 3:1), (3) the operator work load, (4) the addition of group-performance tasks, (5) the total duration of the period of confinement (4 hours, 4 days, and 12, 15, and 30 days), (6) the effects of two days of sleep loss on performance under two work-rest schedules (4-2 and 4-4), (7) the elementary relations between the performance measures obtained and two biomedical measures, and (8) samples of subjects representing different populations (college students, including ROTC students and AF Academy cadets, operational B-52 crews, and Air Force Officers newly graduated from pilot training schools). The results of these studies have been reported by Adams and Chiles (1960; 1961; and by Alluisi et al., 1962; 1963; 1964) in USAF technical reports. In addition, an essentially identical battery has been constructed for use in studying the behavioral effects of infectious diseases (Alluisi & Fulkerson, 1964; Alluisi & Thurmond, 1965); i.e., the "incapacitating" effects of certain illnesses are to be measured in terms of the performances of operators using this multiple-task performance battery to perform "synthetic work" (Alluisi et al., 1966).

The battery includes tasks that were designed to measure (1) watchkeeping, vigilance, and attentive functions, (2) sensory-perceptual functions, (3) memory functions, both short and long term, (4) communication functions, including the reception and transmission of information, and (5) procedural functions that include such things as interpersonal

coordination, cooperation, and organization. The battery as it currently exists has essentially no measures of (6) perceptual-motor functions, but appropriate research to develop a task suitable in this regard is being conducted elsewhere. Finally, the battery has provided only indirect measures of (7) intellectual functions, and the present research was designed to develop a task that would provide direct performance measures of such functioning.

Background in Measuring "Intellectual Functioning"

As the terms are used here, "performance of intellectual functions" refers to the measureable performance of man on tasks, the successful completion of which demand certain mediational processes such as (1) the filtering of irrelevant information received from both his external and internal environments, (2) the encoding of information into forms suitable for processing, storage, and recovery of information from memory, (3) the storage of certain information for both short- and long-term usage, (4) the making of decisions on the basis of the processed information, and (5) the re-encoding of information into forms meaningful to his response system. All of these mediational processes have been studied individually to some extent, but only in the study of man's problem-solving behavior have all of them been investigated in combination.

In the typical problem-solving study, the subject's task is to change a given situation to some specified different situation. There is at least one solution to each problem--a solution that the subject must discover by some means (e.g., by trial and error, or by application of some set of logical or schematic rules). In seeking the solution, the subject must filter irrelevant information; he must also store information about the problem, his search pattern, and the results of his prior searching. Throughout the problem-solving process, the subject must make decisions regarding the formulation and testing of his personal hypotheses concerning the probable solution, and, consequently, he must recover previously stored information and must re-encode information to permit the responses that are used in testing his hypotheses. In short, the typical problem-solving task involves those processes which are believed to be definitive for the performance of intellectual functions. What is needed, then, for a performance test of intellectual functioning is a performance-based measure of what might be called problem-solving activity.

Numerous different tasks have been used in the study of man's problem-solving behavior; detailed descriptions of some 29 of these, representing most of the major tasks used prior to 1953, have been presented by Ray (1955). The majority of these tasks (and of even-earlier tasks not included in Ray's review) appear to have been of the parlor-puzzle or gaming variety, rather than of a performance-measurement nature suitable for experimental use or measurement of the type desired here.

The problem-solving tasks that have appeared in the psychological literature since about 1950 appear to reflect a trend toward the use of

tasks better suited to precise behavioral experimentation. These tasks typically enable the experimenter to present problems of comparable difficulty (which can be specified in some cases) to the same subject. Furthermore, the possible actions that may be taken by a subject are limited, thereby providing the experimenter with information from which he can infer something of what the subject is doing. In many cases, these newer problems permit the subject's solution to be scored on continua that provide more useful information than the pass-fail scores of the earlier tasks. Finally, the trend seems to be toward avoidance of tasks that require extra abilities or special knowledge, and toward use of tasks that have one unique solution per problem; neither condition held true for the earlier tasks (cf. Ray, 1955). Among these recently developed tasks are the following:

- Trouble-shooting task (Fattu & Mech, 1953a; 1953b)
- Modern-logic task (Moore & Anderson, 1954; Anderson, 1957)
- Sequential-dependency task (French, 1954)
- Complex trouble-shooting task (Marx, Goldbeck, & Bernstein, 1956; Goldbeck, Bernstein, Hillix, & Marx, 1957)
- Search task (Ray, 1957)
- Problem-solving-using-information (PSI) task (John & Miller, 1957; John, 1957; Gyr, 1960)
- Light-pattern task (French, 1958; French & Thomas, 1958; Duncan, 1963)
- Fire-control task (Donahoe, 1960)
- Complex search task (Pylyslyn, 1963).

A review of these tasks, and of the results of research conducted with them, has demonstrated that none is suitable for the purposes of the current research. For example, one of the most promising of the tasks is that based on use of the PSI apparatus. With it, the essential intellectual processes are required of the subject--he must decide to conduct certain tests, he must filter irrelevant information from the display and store relevant information concerning certain stimulus-response relations that he has inferred or deduced, and he must re-encode the accumulated information for use in making the responses required. However, the time necessary to reach a solution is relatively long, so that there would be relatively low statistical power in using the PSI task to test differences in performances based on samples of behavior taken, say, in two half-hour periods. Also, the problems presented in the PSI task appear to lack structure, in the sense that a subject may arrive at a correct solution to a given problem in many different ways--each of which might be associated with its own optimal solution time.

What is needed in any task that is to provide sensitive and reliable measures of a subject's intellectual performance is (1) a use of the elements of the problem-solving paradigm, (2) the provision for an adequate number of measures as well as for replications of each measurement during reasonably short intervals of time to permit suitably high reliability, and (3) the possibility of experimental controls of the important variables associated with the subject's performance (the time at which the information sufficient for a solution is presented to the subject, the number of ways in which the solution can be reached, etc.).

The task that has been designed to meet these requirements is a modification of the "code-lock solving" task that is used as a group-performance task in the current versions of the multiple-task performance battery (cf. Alluisi & Fulkerson, 1964; Alluisi et al., 1962, pp. 5-6). It is an individual, rather than a group-performance, task that will be referred to as the COTRAN task (for COde-TRANsformation). It was designed to meet certain criteria of face validity, sensitivity, engineering feasibility, reliability, flexibility, work-load variability, trainability, and control-data availability as defined elsewhere (see Alluisi, 1964; Alluisi & Fulkerson, 1964). The principal data concerning the nature and potential utility of the COTRAN task are presented in the remaining sections of this report.

Method

During the past year, the COTRAN task has been developed and the necessary apparatus has been designed and constructed. In addition, two major experiments have been conducted. In the first of these experiments (COTRAN-I), two of the relevant parameters of the COTRAN task were established and the measures to be used in scoring performance were selected on the basis of a factor analysis of a total of 72 possible measures. In the second study (COTRAN-II), selected measures of COTRAN performance were correlated with measures of general intellectual abilities (both verbal and nonverbal) and with certain specific tests of intellectual characteristics and personality variables; these, in turn, were factor analyzed to provide some insight into the nature of COTRAN--the task, its performance, and its measures.

A description of the COTRAN task will be given in this section, after which the methodology of the two experiments will be presented separately. Likewise, the results of the two experiments will be presented separately in a later section that will be followed by a general discussion of both studies.

The COTRAN Task

The working elements of the COTRAN task are displayed to the operator on a response board and information panel as shown in Figure 1. These elements consist of five response keys arranged to fit the fingers of the

right hand, three primary indicator lights (red, amber, and green) on a sloping panel, and three secondary indicator lights (all blue) on the lower front of the display. The task is performed in three phases.

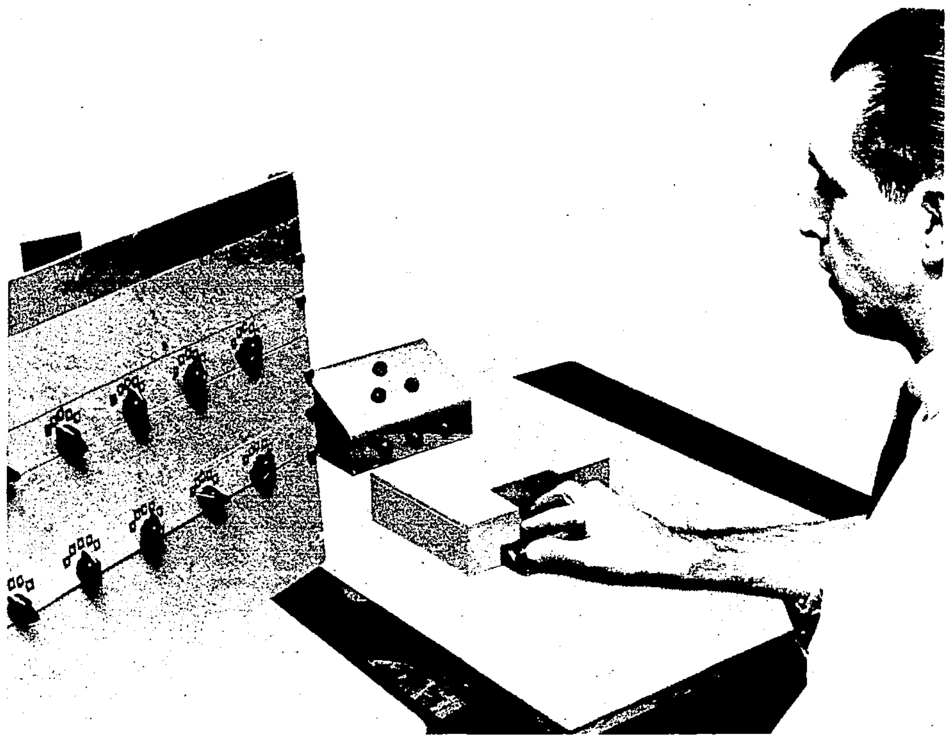

Figure 1. Photograph of COTRAN Apparatus Showing Subject's Memory Aids, Information Panel, and Response Board.

In phase I, the operator is required to discover, by means of a systematic trial-and-error search pattern, the proper sequential order for depressing the five response keys (one for each finger of the right hand). The three indicator lights on the sloping panel provide the information necessary for the discovery of the correct sequence. Illumination of the red light is the signal that a sequence is present and ready to be solved. The amber light is illuminated when the operator depresses any of his response keys, thereby indicating that his response has been registered. When the response key is released, the amber light is extinguished; the red light remains illuminated unless the key that was depressed is the "correct" first response. If the key is the correct

first response, then the red light is extinguished at the same time as the amber light, and it will remain extinguished until an "incorrect" (i.e., out-of-sequence) response is made. When this occurs, the red light will be re-illuminated, and the programming apparatus will be reset automatically to the beginning of the sequence. In order to recommence the search for a solution, then, the correct first response key has to be depressed first, the correct second response key has to be depressed next, etc. When all five response keys have been depressed in the correct order, the green light will be illuminated as a signal that the sequence presented in phase I has been completed. Following a between-phase pause of 30 sec., the green light will go off, the red light will come on, and the operator is presented with phase II of the problem. Phase II is identical to phase I, except, of course, that it involves a different sequence. The left-most blue light is lit during phase I, and the second or middle light is lit during phase II.

During phase III, which begins immediately upon completion of phase II, the right-most blue light is lit and the operator is required to deduce from the sequences (solutions) of phases I and II, the transformation that must have been applied to the sequence of phase I in order for it to have generated the sequence of phase II. That is to say, he has to determine how the phase-I sequence would have had to be changed in order for it to have produced the phase-II sequence. The operator is then required to apply the deduced transformation to the phase-II sequence in order to predict the solution to a third key-pressing sequence; i.e., he has to predict a third sequence, and test his prediction by applying it.

It might be well to call attention to some of the properties of the parts of the task presented in phases I and II. Since all 120 of the possible sequences are used in random order on successive presentations of phase I, the operator has no way of knowing what the correct sequence will be when the problem is presented. Rather than having him search for this sequence in a haphazard manner, the operators are instructed to use consistently a systematic search procedure. That is to say, operators are instructed to initiate their search for each part of the sequence with the left-most available key and search in the direction of the right-most available key. Whereas any systematic search procedure would serve the same purposes, the above procedure was selected to place the keypress work load on the more dexterous thumb, index, and middle fingers (cf. Dvorak, 1936). In addition, with the same procedure's being used by all operators in phases I and II, expectancies can be established as to the number of errors or resets that would be obtained in an ideal solution of each sequence. This, of course, makes possible the future use of a criterion for the assessment of performance in these two phases.

In terms of "face validity," the COTRAN task appears to require the use of the necessary mediational processes. For example, in phases I and II the operator must <u>filter</u> the information that is irrelevant to the discovery of a sequence (e.g., incorrect keypresses) to arrive at the relevant information (the correct sequence). <u>Short-term storage</u> is required; the operator must recall continuously the status of his search

for the correct sequence in phases I and II (i.e., which keys have been included in the sequence and which keys have not been pressed). Upon discovery of the correct sequences in phases I and II, the operator must remember the sequences for later manipulations; i.e., the sequences are placed in long-term storage. In phase III of the task, the operator must not only make decisions as to what transformation is involved in the problem, but he must also re-encode the transformation for application to the phase-III sequence--i.e., into keypresses for the final solution to the problem. Thus, the COTRAN task appears to require the desired elements of behavior, and it should provide measures of the symbolic mediation that is generally defined as intellectual functioning.

Parameters of the COTRAN Task

Given the restriction that no key can appear twice in the same sequence, there are, as previously mentioned, 120 different sequences that can be presented in phase I of the task. Also, there are 119 different sequences that can be presented in phase II, given that the sequences of phases I and II must differ. A breakdown of these 119 sequences indicates that there are ten sequences which change only two elements of the phase-I sequence; stated differently, there are only ten 2-element transformations that may be applied to the phase-I sequence. Likewise, there are twenty 3-element transformations, forty-five 4-element transformations, and forty-four 5-element transformations.

Since the operator must deduce the transformation and apply it to the phase-II sequence in order to arrive at the final solution in phase III, the difficulty of the phase-III solution could be related, in part, to the complexity of the transformation involved. Thus, one possible parametric dimension of the COTRAN task is the complexity of the transformation, or the number of elements involved in the transformation.

It is apparent that the COTRAN task imposes a considerable load upon the operator's memory capacity: he must hold in memory not only the discovered phase-I sequence, but also the phase-II sequence and the current position of his solution attempts in phase III. This memory load could be lessened by providing the operator with a system of memory aids. In other words, memory aids could be provided whereby the operator could record a sequence after it was discovered (e.g., at the end of phase I). He could then forget that sequence and concentrate on the next phase. The use of such a memory-aid system would introduce another possible parametric dimension of the COTRAN task--the number of memory aids available to the operator--and the operator could be provided with no memory aid, one memory aid (for phase I), two memory aids (for phases I and II), or three memory aids (for phases I, II, and III). The ways in which memory aids were used will be described in later sections.

Direct Measures of COTRAN Performance

Each "problem" presented with the COTRAN task requires the solution of all three phases. Thus, the COTRAN operator or subject must complete

three different keypressing sequences correctly in order to solve one problem. The measures of performance directly recorded are as follows:

1. Keypresses (K).--The number of keypressing responses made by the subject in each phase of each problem.

2. Resets (E).--The number of erroneous responses, or "red lights" or "resets" in each phase of each problem.

3. Responding time (RT).--The length of time, in 0.1 sec., between the appearance of the first red light (which indicates the beginning of a sequence) and the appearance of the green light (which indicates the achievement of a correct sequence) in each phase of each problem.

4. Total time (TT).--The length of time between the beginning of one phase to the beginning of the next. This is equivalent to RT plus 30 sec. for phases I and II, and it is exactly equivalent to RT for phase III.

5. Problems (P).--The total number of problems solved by a subject under a given set of conditions, each problem's consisting of three phases or sequences.

6. Sequences (S).--The total number of sequences or phases solved by a subject under a given set of conditions; this must be three times the total number of problems solved, since there are three phases per problem.

Although each of these six direct measures could be taken for each of the three phases in each problem, not all of them were so recorded in both of the two experiments conducted; a listing of the data recorded will be given in the discussion of the methods employed in each of the two experiments. Also, it should be noted that a large number of indirect measures of COTRAN performance could be obtained through the use of various combinations of these direct measures; e.g., Resets/Keypresses. These, too, will be presented in the sections that present the specific methodology of each experiment.

Experiment I (COTRAN-I)

General.--The relevant parameters of the COTRAN task must be determined if the task is to be fully understood. Two factors that might be expected to effect COTRAN performance were investigated in the first experiment: (1) the number of memory aids available and (2) the complexity of the transformations employed.

The results of pilot experimentation indicated that when no memory aid was provided the task was too difficult to be used as a performance-assessment instrument. That is to say, some operators required as long as 20 min. to solve a single problem when provided with no aids for remembering the discovered sequences. Also, all operators chose to use only two memory aids when provided with three aids in the pilot studies. Thus, on the basis of pilot experimentation, it was decided that two memory-aid conditions were to be included for study in COTRAN-I: one memory aid (for phase I) versus two memory aids (for phases I and II).

A second dimension to be studied was formed by use of three different transformation complexities. Because there were only ten 2-element transformations that could be applied to any problem, and because each 2-element transformation would produce a phase-III sequence identical to the original phase-I sequence, it was judged best to omit use of 2-element transformations. Thus, the transformation-complexity dimension was represented at three levels with 3-, 4-, and 5-element transforms.

Experimental design and subjects.--The two memory-aid conditions were combined factorially with the three transformation-complexity conditions in a 2-by-3 design. Fifteen subjects were assigned at random to each of the six cells, with the ratio of males to females held constant at 7:8 in each cell. The subjects were 90 undergraduate students (42 males and 48 females) enrolled in introductory psychology classes at the University of Louisville. Participation in this experiment partially fulfilled a course requirement. The subjects ranged in age from 16 to 29 years, with a median age of 19.

Apparatus.--The apparatus consisted of three basic components used by the subject (response, information, and memory units) and two components used by the experimenter for programming and scoring. The positioning of the response keys was determined from 10 male and 10 female subjects on the basis of measurements of the natural positioning of the fingers of the right hand when at rest; the exact dimensions are given elsewhere (Coates, 1966, Fig. 2).

The six, 1/2-in. diameter jeweled indicator lights on the subject's information panel were mounted as previously shown in Figure 1. The blue lights were used to indicate the phase of the problem on which the subject was working (I to III, from left to right), whereas the red, amber and green lights provided the information necessary for the solution of each phase.

The subject's response and information units were mounted on a 30-by-20 in. response board which in turn was mounted on a 30-by-30-in. table. The top of the table was 27 in. above the floor.

The memory unit enabled the subject to record a discovered sequence. A "memory aid" consisted of five, 5-position, 1-in. diameter, rotary

switches, each of which could be set to point to one of five numbers (1, 2, 3, 4, and 5). Each of the five rotary switches corresponded to a keyboard position: the left-most rotary switch to the thumb, the next left-most switch to the index finger, etc. Therefore, at the end of the phase, the subject would set each of the rotary switches to the number which indicated the position of the key (or finger) in the discovered sequence. For example, the middle rotary switch set on "4" would indicate that the middle finger was the fourth button in the sequence. In the one-memory-aid conditions, the subjects were provided one aid (i.e., one bank of five rotary switches) on which the phase-I sequence could be recorded. In the two-memory-aid conditions, the subjects were provided two aids (i.e., two banks of five rotary switches) on which they recorded both phases I and II. The switches were mounted on a vertical panel 11-by-19 in., on 3-in. centers, with the center switch of the first row 4 in. from the top of the panel. The panel faced the subject from the left of the COTRAN information display and was angled about 45-deg. from normal to facilitate its use.

The experimenter's programming unit consisted of three banks of five, 5-position rotary switches--one bank for each of the three phases of a problem. The experimenter programmed the correct sequences on these banks of rotary switches that were connected electrically to a stepping switch and a series of relays which served to score the correctness of the subject's responses. Thus, in conjunction with the programming unit, the scoring unit permitted the experimenter to monitor accurately the subject's performance. The subject's errors and response times (to the nearest 0.1 sec.) for each phase were recorded on electromechanical counters. An additional counter provided the total number of keypresses made by the subject per problem (i.e., summated over all three phases).

The subject and his apparatus occupied a 5-by-7-ft. experimental room in which an overhead florescent light fixture provided ambient illumination. The experimenter's apparatus was placed in an adjoining room and was connected to the subject's by a single cable. Approximately 70 dB of broadband noise were used in the experimental room to mask the sound of the programming unit and to isolate the subject from other extraneous noises.

Procedure.--Each subject received a standard set of instructions appropriate for the condition to which he had been assigned at random (the instructions are reproduced exactly in Coates, 1966, Appendix C). Each subject was tested on the COTRAN apparatus following the instructions. A phase-I sequence was randomly selected from the 120 possible sequences and entered by the experimenter on the first bank of programming switches. Then, the experimenter randomly selected one of the transformations from the appropriate subpopulation and applied it to the phase-I sequence in order to determine the phase-II sequence. He entered this sequence on the second bank of programming switches, then applied the transformation to that sequence in order to determine

the phase-III sequence which he then entered on the third bank. A 30-sec. "green light" (or no-response) interval between problems and between phases I and II of a given problem was employed throughout the study. Each subject was tested for a total of 1000 sec., exclusive of these 30-sec. intervals. Seven direct measures of COTRAN performance were recorded for each subject: (1) responding time in phase I, (2) in phase II, (3) in phase III, (4) resets in phase I, (5) in phase II, (6) in phase III, and (7) keypresses per problem (i.e., keypresses in phases I, II, and III, combined). In addition, total time could be obtained wherever responding time had been recorded, and the total number of problems solved during the period of testing could be counted and recorded.

Experiment II (COTRAN-II)

General.--The principal objective of COTRAN-II was a factor analysis of the data obtained from a relatively large group of subjects--data that consisted both of measures of COTRAN performances and of scores from a battery of selected paper-and-pencil tests. The measures of COTRAN performances were to be selected on the basis of the results of the first experiment, COTRAN-I, and the paper-and-pencil tests were selected from among three general classes of instruments: (1) tests of general intellectual ability, (2) tests based on factor-analytic studies of intellectual abilities, and (3) tests of personality characteristics. Achievement of this goal would help identify the nature of the COTRAN task and measures, and would indicate the relations between this new task and the more widely used paper-and-pencil tests.

A second goal of this experiment was to obtain estimates of the reliabilities of the measures of performance (selected on the basis of the results of COTRAN-I). A third goal was to re-examine the effects of the transformation-complexity dimension across a total of 18 problems per subject. The final goal was to examine the effects of practice across the 18 problems.

It had been decided that only one of the two memory-aid conditions (that of two memory aids) would be used in COTRAN-II unless the results of COTRAN-I indicated that generalization between the one and two memory-aid conditions could not be made (in which case the study would have had to have been expanded to include both conditions). Each subject served in two sessions: (1) a COTRAN-performance session, and (2) a session in which the battery of paper-and-pencil tests was administered.

Subjects.--For both sessions of COTRAN-II, the subjects were 84 undergraduate students (50 males and 34 females) from various psychology classes at the University of Louisville. The ages of the subjects ranged from 17 to 30 years, with a median of 19. Each subject was paid ten dollars for his participation in the experiment.

COTRAN-performance session.--The apparatus and physical conditions in the COTRAN-performance session of COTRAN-II were identical to those of the two-memory-aid conditions in COTRAN-I. Here, however, a total of 18 problems was presented to each subject and only the two-memory-aid condition was used. The 18 problems consisted of 6 blocks of 3 problems each; the 3 problems within each block consisted of one each 3-, 4-, and 5-element transformation. A Latin-square was used to counterbalance the order of transformation complexities within each block of problems over the six blocks for each set of six subjects. A 30-sec. interval was again used between phases I and II of a problem, and between problems. In addition, the subject was given a 5-min. rest after he had completed half of the 18 problems--i.e., after the ninth problem or third block. In all other respects the procedure was identical to that of COTRAN-I.

Paper-and-pencil test session.--A total of ten paper-and-pencil tests was administered during this session. A review of these tests is given elsewhere along with the logic that led to their selection for use here (Coates, 1966, Appendix D). These tests provided a total of 32 scores for each subject. The tests selected are listed below along with identification of the scores obtained with the tests and the coded names (on the right) that will be used to refer to these in subsequent sections.

(a) Tests of intellectual ability

(1) General tests

Raven Progressive Matrices, 1938.................Raven
Ohio State Psychological Test,
Part I ....OSPT-I
Part II ....OSPT-II
Part III ....OSPT-III
Total ....OSPT-Total

(2) Tests based on factor-analytic studies

Apparatus....................................FAS-Appr
Associational Fluency........................FAS-AssocFlu
Logical Reasoning............................FAS-LogReas
Object Synthesis.............................FAS-ObjSyn
Seeing Problems..............................FAS-SeeProb
Ship Destination.............................FAS-ShipDest

(b) Tests of personality characteristics

(1) Allport-Vernon Study of Values (Scores)

Theoretical..................................AV-Theo
Economic.....................................AV-Econ
Aesthetic....................................AV-Aesth
Social.......................................AV-Soc
Political....................................AV-Pol
Religious....................................AV-Rel

(2) Edwards Personal Preference Schedule (Scores)

Achievement	EPPS-Ach
Deference	EPPS-Def
Order	EPPS-Ord
Exhibition	EPPS-Exh
Autonomy	EPPS-Aut
Affiliation	EPPS-Aff
Intraception	EPPS-Int
Succorance	EPPS-Suc
Dominance	EPPS-Dom
Abasement	EPPS-Aba
Nurturance	EPPS-Nur
Change	EPPS-Chg
Endurance	EPPS-End
Heterosexuality	EPPS-Het
Aggression	EPPS-Agg

A 6-hr. testing session was necessary for the group administration of the tests. The tests of intellectual abilities were administered during a 4-hr. morning session, whereas the tests of personality characteristics were administered during a 2-hr. afternoon session. Testing procedures prescribed in the testing manuals were observed for all tests except the Ohio State Psychological Test; this test was used as a 1-hr. speed test, rather than as a power test. An additional set of test scores on the Scholastic Aptitude Test (SAT) was obtained for 66 of the 84 subjects. These test scores were made available through the Office of the Registrar at the University of Louisville.

Results

The results of COTRAN-I and COTRAN-II will be presented separately in this section. First, however, reference is made to the prior section on "Direct Measures of COTRAN Performance" (p. 8) and to the abbreviations assigned there to the direct measures; namely, *K* for keypresses, *E* for errors or resets, *RT* for responding time, *TT* for total time, *P* for problems, and *S* for sequences. The abbreviation will be connected with a hyphen to a numeral to indicate the phase to which reference is made. Thus, K-1 will represent the number of keypresses in phase I; E-123 will represent the number of resets in phases I, II, and III; etc.

Experiment I (COTRAN-I)

Seventy-two measures of COTRAN performance were used in the analysis of the results of COTRAN-I. These 72 measures are presented in Table 1; they will be referred to by number throughout the remainder of this report. It should be noted that roughly half of the measures are reciprocal transformations of the other half; these transformations were used because

Table 1

Identification and Definition of the 72 Measures of COTRAN Performance Analyzed in COTRAN-I

Measure Number	Algebraic Definition	Measure Number	Algebraic Definition
1	$(E\text{-}3)/\frac{1}{2}(E\text{-}1+E\text{-}2)$	--	--
2	$(RT\text{-}3)/\frac{1}{2}(RT\text{-}1+RT\text{-}2)$	--	--
3	$(TT\text{-}3)/\frac{1}{2}(TT\text{-}1+TT\text{-}2)$	--	--
4	(E-123)/(K-123)	38	1/#4
5	(E-1)/(S-1)	39	1/#5
6	(E-2)/(S-2)	40	1/#6
7	(E-12)/(S-12)	41	1/#7
8	(E-3)/(S-3)	42	1/#8
9	(E-123)/(S-123)	43	1/#9
10	(E-1)/(RT-1)	44	1/#10
11	(E-2)/(RT-2)	45	1/#11
12	(E-12)/(RT-12)	46	1/#12
13(18)	(E-3)/(RT-3)	47(52)	1/#13
14	(E-123)/(RT-123)	48	1/#14
15	(E-1)/(TT-1)	49	1/#15
16	(E-2)/(TT-2)	50	1/#16
17	(E-12)/(TT-12)	51	1/#17
18(13)	(E-3)/(TT-3)	52(47)	1/#18
19	(E-123)/(TT-123)	53	1/#19
20	(K-123)/(S-123)	54	1/#20
21	(K-123)/(RT-123)	55	1/#21
22	(K-123)/(TT-123)	56	1/#22
23	(S-1)/(RT-1)	57	1/#23
24	(S-2)/(RT-2)	58	1/#24
25	(S-12)/(RT-12)	59	1/#25
26(31)	(S-3)/(RT-3)	60(65)	1/#26
27	(S-123)/(RT-123)	61	1/#27
28	(S-1)/(TT-1)	62	1/#28
29	(S-2)/(TT-2)	63	1/#29
30	(S-12)/(TT-12)	64	1/#30
31(26)	(S-3)/(TT-3)	65(60)	1/#31
32	(S-123)/(TT-123)	66	1/#32
33	(RT-1)/(TT-1)	67	1/#33
34	(RT-2)/(TT-2)	68	1/#34
35	(RT-12)/(TT-12)	69	1/#35
36	(RT-3)/(TT-3)	70	1/#36
37	(RT-123)/(TT-123)	71	1/#37
--	--	72	Equiv. Rate*

K--keypresses; E--errors or resets; RT--responding time; TT--total time; P--problems; S--sequences, or 3 x P; numeral(s) following the hyphen indicate the phase(s) included. Measures #36 and #70 equal unity.

*Equiv. Rate = equivocation rate = 1.38138 (#21-5(#27)), in bits/sec.

of their nonlinear nature and in order to permit selection of the highest loadings to represent the factors.

A score was obtained for each of the subjects using each of the 72 measures defined in Table 1. The 72 measures were then intercorrelated three ways: (1) over the 45 subjects who used one memory aid, (2) over the 45 subjects who used two memory aids, and (3) over the combined data of the 90 subjects who, therefore, used either one or two memory aids. Finally, these intercorrelations were factor analyzed (principal axes) and rotated (Varimax) with use of a large digital computer (IBM 7094). The computer failed to produce the appropriate factor loadings for measure #55 in the one-memory-aid conditions, and measure #21 in the two-memory-aid condition. No reason could be discovered for the omission, and since in each case the appropriate reciprocal was included, the factor analyses were computed without the missing data. Both measures were included in the data of the analysis that combined the data of the 90 subjects in both memory-aid conditions. Finally, it should be noted that in COTRAN-I, measure #36 and its reciprocal, measure #70, were equal to unity in all cases; thus, these measures contributed nothing to the total variance, and, as expected, had zero loadings on all extracted (and rotated) factors.

The percentages of total variance explained with each of the first five factors extracted and rotated under the three conditons are shown in Table 2. The coefficients of correlation between the corresponding factors in the three analyses are given in Table 3. The zero loadings of measures #36 and #70 were omitted from all the computations of these correlations, and the missing data discussed in the preceding paragraph (#21 with two memory aids, and #55 with one memory aid) were also omitted. Thus, the A-B correlation is based on 68 measures, whereas the A-C and B-C correlations are each based on 69 measures.

It is evident from the data of Tables 2 and 3 that the factorial structure was essentially identical in the three analyses, although there is also an indication that factor-V under the two-memory-aid condition is somewhat different from the same factor under the one-memory-aid condition and the combined analysis. Because of this difference and because the two-memory-aid condition is used in the later experiment (COTRAN-II), the loadings obtained in its analysis are presented in Table 4 instead of the loadings of the combined condition that involved more subjects.

The factorial structure produced by the Varimax rotations appears to be sufficiently clear to require no further rotations for identification. The factors are identified in the following paragraphs, and measures are selected to represent the factors in future analyses; comments on the interpretation of the factors will be postponed to the discussion section.

General Sequences per Unit Time--Factor I.--The first factor can be identified by its high loadings on measures #28 and #30. Measure #28 is the ratio of the number of phase-I sequences completed (or the number of

Table 2

Percentages of Total Variance Explained by First Five Factors in Each of Three Analyses of COTRAN-I

Factor	Memory-Aid Condition		
	One	Two	Combined
I	32.05	41.82	30.95
II	20.36	19.25	19.61
III	8.77	7.16	6.91
IV	14.05	12.93	13.46
V	11.46	6.82	12.57
Total	86.69	87.98	83.50

Table 3

Correlations of Loadings of Corresponding Varimax-Rotated Factors in Three Analyses of COTRAN-I

Factor	Conditions Correlated*		
	A-B	A-C	B-C
I	.941	.995	.953
II	.926	.995	.953
III	.901	.938	.932
IV	.834	.949	.961
V	.638	.989	.661

*A--one memory aid (45 subjects); B--two memory aids (45 subjects; C--combined, A and B (90 subjects).

Table 4

Factor Loadings of the 72 COTRAN-I Measures After Varimax Rotation: Data of the Two-Memory-Aid Condition#

Measure (& Factor)	I	II	III	IV	V	Measure (& Factor)	I	II	III	IV	V
1(III)	-19	-09	80	56	08	---	---	---	---	---	---
2	-58	-01	20	74	12	---	---	---	---	---	---
3(IV)	-33	-06	24	89	06	---	---	---	---	---	---
4	51	65	20	22	-09	38	-49	-61	-18	-25	15
5	64	67	10	-08	24	39	-71	-56	06	15	-28
6	45	36	-03	-03	-80	40(V)	-35	-36	01	10	83
7	69	68	07	-08	-12	41	-71	-60	00	13	31
8(III)	08	16	84	41	05	42	-08	-06	-26	-46	05
9	61	64	41	11	-08	43	-62	-57	-37	-23	26
10	-70	60	-08	-24	-04	44	63	-65	11	15	-02
11	-79	47	11	-12	-13	45	76	-56	-11	07	12
12	-78	56	02	-19	-09	46	75	-64	00	11	05
13	-02	20	89	13	03	47	06	-08	-38	-27	-03
14	-76	58	16	-16	-09	48	74	-64	-14	08	03
15	16	92	-06	-20	21	49	-02	-87	12	22	-21
16	-34	65	08	-13	-62	50	27	-63	-06	12	66
17(II)	-09	94	01	-20	-21	51	15	-92	00	18	25
18	-02	20	89	13	03	52	05	-08	-38	-27	-03
19	-08	88	38	-11	-17	53	17	-88	-32	08	20
20	62	55	45	08	-14	54	-62	-50	-44	-15	22
21	*	*	*	*	*	55	38	-39	-10	82	03
22	-24	52	22	-76	-11	56	20	-52	-21	76	09
23	-95	03	-02	-08	-21	57	87	-30	17	-02	21
24	-84	11	08	-01	43	58	78	-09	-10	03	-54
25	-97	08	03	-05	10	59	96	-11	00	01	-14
26	-27	02	-24	-88	06	60	17	-01	30	91	-03
27	-95	07	-02	-23	10	61	95	10	06	16	-15
28(I)	-95	-10	-05	-02	-21	62	87	30	17	-02	21
29(V)	-84	09	09	-03	50	63	78	-09	-10	03	-54
30(I)	-99	-02	02	-02	12	64	96	12	01	00	-14
31	-27	02	-23	-88	06	65(IV)	17	-01	30	91	-03
32	-81	00	-13	-53	12	66	84	09	16	44	-14
33	95	10	05	02	21	67	-95	03	-02	-08	-21
34	84	-09	-09	03	-50	68	-84	11	08	-01	43
35	99	02	-02	02	-12	69	-97	08	03	-05	10
36	*	*	*	*	*	70	*	*	*	*	*
37	99	02	-02	02	-12	71	-99	03	03	-04	11
--	--	--	--	--	--	72	07	41	11	-86	-15

#For ease of reading, the decimal point that should precede each entry in the table has been omitted.

*Data of measure #21 were unaccountably omitted in the computer output; measures #36 and #70 were unit constant for each subject and so contributed nothing to the total variance, with resultant zero loadings on all factors in all analyses.

problems completed) to the total time spent in phase I of the problems. Measure #30 is the ratio of the number of phase-I and phase-II sequences completed (or twice the number of problems completed) to the total time spent in phases I and II. The loadings are -.95 and -.99, respectively. Thus, a low score (in sequences per unit time), which would represent a long time in phases I and II, would obtain a high score on this factor, whereas a high score, which would represent a short time per sequence, would obtain a low score on this factor. Note also that the factor is a general factor for phases I and II, but that it does not include high loadings generally for phase III--the "problem-solving" phase. Measure #31, which is the comparable phase-III measure is loaded only -.27 on this factor.

General Error Rate--Factor II.--The second factor can be identified by its high loadings on the error-rate measures, especially on measure #17, which is the ratio of errors or resets in phases I and II to the total time spent in these two phases of COTRAN performance. The loading is +.94; thus, a high score (in resets per unit time) represents a high error or reset rate, whereas a low score represents a low error or reset rate.

Errors in Problem Solving--Factor III.--The third factor may be represented principally by the high loadings of measures #1 and #8. Measure #1 is the ratio of errors or resets in phase III to the mean errors or resets in phases I and II. Measure #8 is the ratio of the errors or resets in phase III to the total number of problems solved. The loadings are +.80 and +.84, respectively. High scores on these measures would indicate relatively high numbers of errors in phase III.

Time in Problem Solving--Factor IV.--The fourth factor is identified principally by the high loadings of measures #3 and #65. Measure #3 is the ratio of the total time spent in phase III to the mean of the total time spent in phases I and II. Measure #65 is the ratio of the total time spent in phase III to the number of phase-III sequences completed (or, the average time in phase III per problem). The loadings are +.89 and +.91, respectively.

Speed and Accuracy in Phase II--Factor V.--The fifth and final factor apparently represents speed and accuracy in phase-II solutions, and, thereby, represents a group factor isolated from the more general factors I and II. The principal measures that will be used to represent this factor are measures #29 and #40. Measure #29 is the ratio of the number of phase-II sequences solved (or the number of problems solved) to the total time spent in phase-II solutions. It represents for phase II what measures #28 and #30 (see factor I) represent for phases I, and I and II combined, respectively. Measure #40 is the ratio of the number of phase-II sequences completed (or problems solved) to the total number of errors or resets made during phase-II solutions; it is to phase II what the reciprocal of measure #8 (see factor III) is to phase III. The loadings of measures #29 and #40 on factor V are +.50 and +.83, respectively. (It should be noted that measure

#29 is also highly loaded on Factor I under the two-memory-aid condition for which data are presented in Table 4; this was not the case for the other two conditions where this measure's loadings on factors I and V were essentially reversed.)

An analysis of variance was computed with the data of each of the nine measures selected as representative of the factorial structure of the full set of 72 measures. Each of these analyses followed the 2-by-3 factorial design represented by the two memory-aid and three number-of-transformation conditions. These analyses of variance are summarized in Table 5.

Table 5

Summaries of Analyses of Variance of Nine Selected Measures that Represent the Five Factors of COTRAN-I Performance

Measure Number (& Factor)	Memory Aids (1)		Transformations (2)		MxT (2)		Within (84)
	Mean Square	F	Mean Square	F	Mean Square	F	Mean Square
28(I)[1]	2.4336	1.746	1.6707	1.199	1.3726	---	1.3939
30(I)[2]	13.1484	1.403	7.0515	---	9.2055	---	9.3719
17(II)[4]	1.0671	---	2.9254	---	7.4191	1.826	4.0639
1(III)[1]	38.0479	25.596**	0.0328	---	2.4538	1.715	1.4306
8(III)	209.3978	28.409***	0.0979	---	9.9419	1.349	7.3708
3(IV)[1]	97.8121	12.489**	16.2010	2.069	33.8343	4.320*	7.8316
65(IV)[5]	74.9725	15.855**	11.5987	2.453	13.2560	2.803	4.7287
29(V)[4]	5.1840	---	11.3701	1.233	5.9963	---	9.2216
40(V)[3]	0.4900	---	0.8215	---	2.3924	1.228	1.9483

1--Mean squares multiplied by 10
2--Mean squares multiplied by 100
3--Mean squares multiplied by 1000
4--Mean squares multiplied by 10,000
5--Mean squares divided by 1000

*$p < .05$
**$p < .01$
***$p < .001$

Except for one statistically significant interaction (obtained with measure #3), the only significant results obtained were the differences attributable to the memory-aids conditions with the four measures that represent factors III and IV--the problem-solving factors (measures #1, #8, #3, and #65).

In each of these cases, the better performance was obtained under the two-memory-aid condition; this is shown in Table 6 where the means of the two conditions are given for each of the four measures.

Table 6

Mean Performance Obtained with One and with Two Memory Aids in COTRAN-I: Data of Four Measures Wherein the Differences are Statistically Significant*

Measure Number (& Factor)	Unit of Measure**	Memory-Aid Condition	
		One	Two
1(III)	Absolute Number; Relative Errors in Phase III	.840	.429
8(III)	Errors in Phase III per Problem	5.815	2.764
3(IV)	Absolute Number; Relative Time in Phase III	2.148	1.489
65(IV)	Time in Phase III per Problem (sec.)	154.313	96.589

*See Table 5 for levels of significance
**See Table 2 for algebraic definition of the measures.

On the basis of these results, it was decided, as indicated earlier, that the population study which would include a relatively large number of subjects (84) and 6 hours of testing with paper-and-pencil tests of general intellectual abilities, specific factor-analytically identified abilities, and personality characteristics, would employ the two-memory-aid condition--the condition that tended to maximize the subject's performance. The data previously presented in Tables 2 and 3 seem to indicate that except for the levels of performance obtained in the two conditions the results are essentially the same. This means that the results obtained with two memory aids should generalize to a one-memory-aid condition, unless some later results indicate otherwise. Thus, the results of COTRAN-II, which are reported below, are based on COTRAN performances with two memory aids available to the subjects.

Experiment II (COTRAN-II)

Seventy-five measures were employed in the analysis of the results of COTRAN-II. As shown in Table 7, these included 43 measures of COTRAN performance as previously defined in Table 1, and 32 measures derived from several paper-and-pencil tests (see pps. 13 and 14). These 75 measures will be referred to throughout this section by the numbers assigned in Table 7.

The limit of a total of 75 measures was set by the computer storage and program available. Because it was desired to include all 32 of the measures from the paper-and-pencil tests, selection had to be made among the previously used 72 measures of COTRAN performance. The 43 measures selected include all nine of the factor-reference measures selected on the basis of COTRAN-I, and all of the original measures in either direct or reciprocal form, but not necessarily in both.

A score was obtained for each of the 84 subjects using each of the 75 measures defined in Table 7. The 75 measures were then intercorrelated, and these intercorrelations were factor analyzed (principal axes) and rotated (Varimax) with use of a large digital computer (IBM 7094). As was the case in the prior analysis, the computer failed to produce the appropriate factor loadings for two measures, #15 and #18, so no results are reported for these measures in the analyses that follow. (Again, no reason could be found for the omission, and a second run of the program produced identical results!)

The first eight factors that were extracted and rotated with the computer program (Varimax rotations, as indicated earlier) were identifiable as representing the five factors of COTRAN performance as identified in COTRAN-I, and three factors related to the paper-and-pencil tests. In the presentations that follow, the factors have been re-ordered so that the first five (I-V) correspond to the five factors from COTRAN-I, and the remaining three (VI-VIII) represent the paper-and-pencil tests. Factors II and V were further rotated against factor VIII to maximize their correspondence with the matching factors in COTRAN-I; the remaining factors were left in their Varimax solutions.

The percentages of total variance explained with each of these eight factors are shown in table 8. Also shown in the table is the coefficient of correlation between the corresponding COTRAN-I and COTRAN-II factors; these correlations range between +.772 and +.979, and are contained within the range of correlations reported in Table 3 for the different conditions of COTRAN-I (+.638 to +.995). Thus, it can be concluded that the first five factors of COTRAN-II are essentially the same as the five factors of COTRAN-I, and they apparently do represent COTRAN performance factors.

Table 7

Identification of 75 Measures of COTRAN and Paper-and-Pencil Test Performance Analyzed in COTRAN-II*

Measure Number	Prior Identification	Measure Number	Prior Identification
1	# 1	39	#56
2	# 2	40	#58
3	# 3	41	#63
4	# 4	42	#65
5	# 5	43	#72
6	# 6	44	Raven
7	# 7	45	OSPT-I
8	# 8	46	OSPT-II
9	# 9	47	OSPT-III
10	#10	48	OSPT-Total
11	#11	49	FAS-Appr
12	#12	50	FAS-AssocFlu
13	#13	51	FAS-LogReas
14	#14	52	FAS-ObjSyn
15	#15	53	FAS-SeeProb
16	#16	54	FAS-ShipDest
17	#17	55	AV-Theo
18	#19	56	AV-Econ
19	#20	57	AV-Aesth
20	#23	58	AV-Soc
21	#24	59	AV-Pol
22	#25	60	AV-Rel
23	#26	61	EPPS-Ach
24	#27	62	EPPS-Def
25	#28	63	EPPS-Ord
26	#29	64	EPPS-Exh
27	#30	65	EPPS-Aut
28	#32	66	EPPS-Aff
29	#33	67	EPPS-Int
30	#34	68	EPPS-Suc
31	#35	69	EPPS-Dom
32	#37	70	EPPS-Aba
33	#40	71	EPPS-Nur
34	#41	72	EPPS-Chg
35	#42	73	EPPS-End
36	#47	74	EPPS-Het
37	#50	75	EPPS-Agg
38	#55	--	--

*See Table 1 (p.15) for prior identification of the COTRAN-performance measures, and the end of the "Method" section (p.13) for prior identification of the measures obtained with the paper-and-pencil tests.

Table 8

Percentages of Total Variance Explained by First Eight Factors in COTRAN-II and Correlation with Five COTRAN-I Factors

Factor*	Percentage of Total Variance	Coefficient of Correlation#
I	28.991	.979
II	6.494	.791
III	12.841	.772
IV	8.612	.974
V	3.732	.833
VI	6.922	---
VII	5.646	---
VIII	4.338	---
Total	77.556	---

*Factors have been reordered so that I-V correspond to the five factors in COTRAN-I.

#Although 43 measures were common to both COTRAN-I and COTRAN-II analyses, measures #15 and #18 were omitted in the computer output of COTRAN-II so that each correlation is based on N = 41.

The loadings of the 75 COTRAN-II measures on the five COTRAN factors are given in Table 9. The loadings of these measures on the three factors related to performances on the paper-and-pencil tests are given in Table 10. The COTRAN-I numerical identification of the reference measures has been placed in parentheses next to the COTRAN-II identification of the nine reference measures, and letters have been placed in parentheses following the identifications of the paper-and-pencil tests; R for Raven, O for the Ohio State Psychological Test, F for the six tests based on factorial studies, AV for the Allport-Vernon, and E for the Edwards tests.

Factors I through V have identifications here in COTRAN-II essentially identical to their identifications in COTRAN-I (see pp. 16-19); they appear to need no further explanation at this point. The remaining three factors, however, have no counterpart in the prior experiment. These three factors will be identified in the following paragraphs.

Verbal Intelligence--Factor VI.--This factor can be identified by the high positive loadings (+.81 to +.95) of the four scores obtained with the Ohio State Psychological Test--a predictor of academic success that is highly verbal in nature. The loadings of the other tests of intelligence

Table 9

Factor Loadings of the 75 COTRAN-II Measures: Data of the Five COTRAN Factors#

Measure	I	II	III	IV	V	Measure	I	II	III	IV	V
1(1)	-05	-03	82	47	05	39	41	-34	55	54	19
2	-66	01	11	69	07	40	92	11	13	01	-20
3(3)	-30	-01	21	89	08	41	92	11	13	01	-20
4	31	39	73	18	-07	42(65)	13	00	33	88	07
5	43	28	73	-11	21	43	-15	25	54	-68	-22
6	53	58	30	-06	-46	44(R)	-40	-22	-31	08	-07
7	55	50	61	-10	-14	45(0)	01	00	-05	03	09
8(8)	09	08	88	35	12	46(0)	-18	15	-07	05	14
9	37	33	83	13	-02	47(0)	-17	-13	-04	04	-04
10	-89	24	27	-01	-08	48(0)	-16	02	-06	05	07
11	-89	34	15	-11	-13	49(F)	-36	-19	-10	-08	00
12	-91	29	21	-06	-10	50(F)	-11	00	-10	04	18
13	-04	08	93	01	-04	51(F)	01	-14	15	-22	-26
14	-84	29	41	-05	-10	52(F)	03	-16	23	11	-16
15	*	*	*	*	*	53(F)	-07	-11	-07	-17	-08
16	-36	72	30	-10	-44	54(F)	-11	-01	09	-09	-04
17(17)	-42	62	55	-08	-21	55(AV)	-24	-12	02	-21	-02
18	*	*	*	*	*	56(AV)	-10	-05	10	-05	04
19	39	29	82	12	-06	57(AV)	12	-21	11	12	-28
20	-94	04	-12	04	-13	58(AV)	05	11	-09	08	-25
21	-96	-03	-03	-07	13	59(AV)	07	04	01	-13	01
22	-98	00	-08	-01	01	60(AV)	13	-03	-13	20	03
23	-10	01	-29	-90	-04	61(E)	-28	-28	10	-03	-29
24	-95	01	-14	-22	00	62(E)	-10	-06	18	-01	-04
25(28)	-93	01	-21	09	-14	63(E)	10	00	00	-13	-01
26(29)	-96	-07	-09	-04	18	64(E)	-06	16	-16	17	-14
27(30)	-98	-03	-15	02	03	65(E)	07	34	-10	17	05
28	-68	-01	-30	-63	-02	66(E)	-03	-05	11	-06	-01
29	93	01	21	-09	14	67(E)	14	22	22	07	41
30	96	07	09	04	-18	68(E)	-01	-33	12	08	-24
31	98	03	15	-02	-03	69(E)	01	20	-10	-05	04
32	98	03	15	-02	-03	70(E)	-13	-14	-01	-01	-11
33(40)	-51	59	-30	02	51	71(E)	-03	-03	-16	-10	12
34	-57	-50	-57	08	21	72(E)	19	07	12	-08	07
35	05	07	-43	-49	39	73(E)	01	-17	-04	-12	-18
36	04	04	-49	-43	41	74(E)	-17	-02	02	-02	00
37	36	-71	-29	07	46	75(E)	06	11	-26	10	16
38	61	-10	-25	64	13	--	--	--	--	--	--

#For ease of reading, the decimal point that should precede each entry in the table has been omitted. Factors II and V have been rotated to match corresponding factors in COTRAN-I; all other factors are Varimax rotations.

*Data of measures #15 and #18 were unaccountably omitted in the computer output. See text (p.24) for meaning of parenthetical entries.

Table 10

Factor Loadings of the 75 COTRAN-II Measures: Data of The Three Factors Related to Paper-and-Pencil Test Performance[#]

Measure	VI	VII	VIII	Measure	VI	VII	VIII
1(1)	-06	03	00	39	02	15	-02
2	03	04	-07	40	-06	03	01
3(3)	01	05	-09	41	-06	03	01
4	-11	08	02	42(65)	-03	06	-09
5	-07	-02	-03	43	-04	-08	07
6	-09	-02	-02	44(R)	19	-10	12
7	-09	-02	-02	45(0)	86	-13	-02
8(8)	-07	-02	00	46(0)	84	13	-08
9	-09	-02	-01	47(0)	81	22	-08
10	06	-02	02	48(0)	95	13	-08
11	00	-01	-02	49(F)	32	-24	07
12	03	-01	00	50(F)	35	02	09
13	-04	02	06	51(F)	13	-16	-08
14	02	-01	02	52(F)	30	-03	09
15	*	*	*	53(F)	53	08	-11
16	-07	-06	-03	54(F)	36	-13	-22
17(17)	-05	-05	-03	55(AV)	13	-26	-04
18	*	*	*	56(AV)	-14	-61	00
19	-08	-06	-04	57(AV)	18	31	-12
20	10	-04	04	58(AV)	10	52	-44
21	04	03	-01	59(AV)	-17	-65	12
22	07	-01	01	60(AV)	-12	53	22
23	-01	-09	10	61(E)	10	-11	24
24	07	-02	04	62(E)	-24	21	48
25(28)	09	-05	03	63(E)	-26	07	66
26(29)	05	-01	-02	64(E)	21	-33	16
27(30)	07	-03	01	65(E)	11	-45	-16
28	04	-08	08	66(E)	-01	26	-51
29	-09	05	-03	67(E)	17	45	08
30	-05	01	02	68(E)	-18	01	-57
31	-07	03	-01	69(E)	35	-25	16
32	-07	03	-01	70(E)	-37	55	-19
33(40)	09	05	01	71(E)	-09	56	-62
34	10	00	03	72(E)	08	-40	-05
35	-08	-13	-17	73(E)	-03	21	73
36	-06	-09	-15	74(E)	-09	-51	-22
37	05	07	03	75(E)	12	-36	03
38	-01	16	-05	--	--	--	--

[#]For ease of reading, the decimal point that should precede each entry in the table has been omitted. Factors VI and VII are Varimax rotations: Factor VIII has been rotated with Factor V of Table 9 (p.25).

*Data of measures #15 and #18 were unaccountably omitted in the computer output.

(both the Raven and the six tests based on prior factor-analytic studies of intellectual abilities) are positive in sign, but range from low to moderately high (+.13 to +.53, with a median of +.32). Thus, this factor is clearly one of verbal intelligence.

Social-Religious vs. Political-Economic Values--Factor VII.--The first of the two personality factors appears to be bipolar. Moderately high positive loadings of +.52 and +.53 were obtained for the social and religious value scales of the Allport-Vernon test, respectively (measures #58 and #60). On the other hand, moderately high negative loadings of -.61 and -.65 were obtained for the economic and political value scales of the same test (measures #56 and #59). Three of the scores from the Edwards test were also loaded moderately highly on this factor; namely, measures #70, #71, and #74, with loadings of +.55, +.56, and -.51, respectively.

Internal-External Motivation--Factor VIII.--Scores from the Edwards test provide the only sets of moderately high loadings on this factor, which also appears to be bipolar. Measures #63 and #73, "order" and "endurance," are positive with loadings of +.66 and +.73, respectively. Measures #66, #68, and #71 (representing the "affiliation," "succorance," and "nurturance" scores) are negative with loadings of -.51, -.57, and -.62, respectively. The two positively loaded scores are associated with characteristics that are relatively independent of other persons (thus, "internal"), whereas the three negatively loaded scores are associated with characteristics that are dependent on other persons ("external").

The identifications of these last two factors, the personality-variable factors, may be considered tentative. Although the identifications appear to be clear, other interpretations might be possible. The important point to be made, however, is that these factors are orthogonal to the five COTRAN factors (and to the verbal-intelligence factor), with essentially zero loadings of the COTRAN measures on each of the three. "Personality," per se, appears not to effect COTRAN performance. The same can be said for "verbal intelligence."

On the other hand, it may be concluded that "nonverbal intelligence," as represented by the Raven test, is related to COTRAN performance: the Raven (measure #44) has loadings of -.40 and -.31 on factors I and III, respectively. Because of this, the COTRAN task has been identified as providing measures of "nonverbal mediation"--i.e., that part of intellectual functioning which is represented, in part, by performance on nonverbal tests of intelligence such as the Raven. This is further supported by the +.23 loading of the Object Synthesis test on factor III.

It may be recalled that the analyses of variance of the nine representative measures in COTRAN-I indicated that only those measures which represented factors III and IV--the problem-solving factors--produced statistically significant results. In the present experiment, analyses of variance were computed with the data of measures #8 and #42 (corresponding to COTRAN-I measures #8 and #65, respectively)--measures that represent factors III and IV. Each of the two analyses followed the 6-by-3-by-84 factorial design that

combined blocks-of-trials with numbers-of-transformations and subjects. Summaries of these analyses are given in Table 11. It is evident from this table and from the data of Figure 2 that practice effects were present and that asymptotic performance had not been reached in the 18 problems, or 6 blocks of 3 problems each.

Table 11

Summaries of Analyses of Variance of Two Selected Measures That Represent the Problem-Solving (Phase-III) Factors of COTRAN-II Performance

Source of Variation	df	Measure 8(8)		Measure 42(65)	
		Mean Square	F	Mean Square	F
Blocks (B)	5	163.009	8.084**	118140.148	59.369***
Transforms (T)	2	13.060	---	1885.031	1.022
BxT	10	4.994	n.t.	626.723	---
Subjects	83	68.331	n.t.	5314.356	n.t.
BxS	415	20.165	n.t.	1989.917	n.t.
TxS	166	16.798	n.t.	1844.303	n.t.
BxTxS	830	14.142	n.t.	1079.970	n.t.
Total	1511	(29456.9715)#	---	(3070174.946)#	---

**$P < .01$; ***$P < .0001$; n.t.--no test possible.

#Sum of squares.

Reliability of the COTRAN measures.--In order to assess the statistical reliability of the nine representative measures of COTRAN performance, a series of odd-even reliability coefficients was computed. For each of these, each subject's data were summarized over the odd-numbered blocks of trials (1, 3, and 5) and over the even-numbered blocks (2, 4, and 6). These summary data were then correlated, over the 84 subjects; the resultant reliability coefficients are given in Table 12 along with the corrected coefficients obtained by application of the Spearman-Brown formula.

It is apparent from the data of Table 12 that the nine selected measures of COTRAN performance are acceptably high in reliability. The corrected reliability coefficients range from .479 to .941, with all except one of the measure's being greater than .65 in reliability.

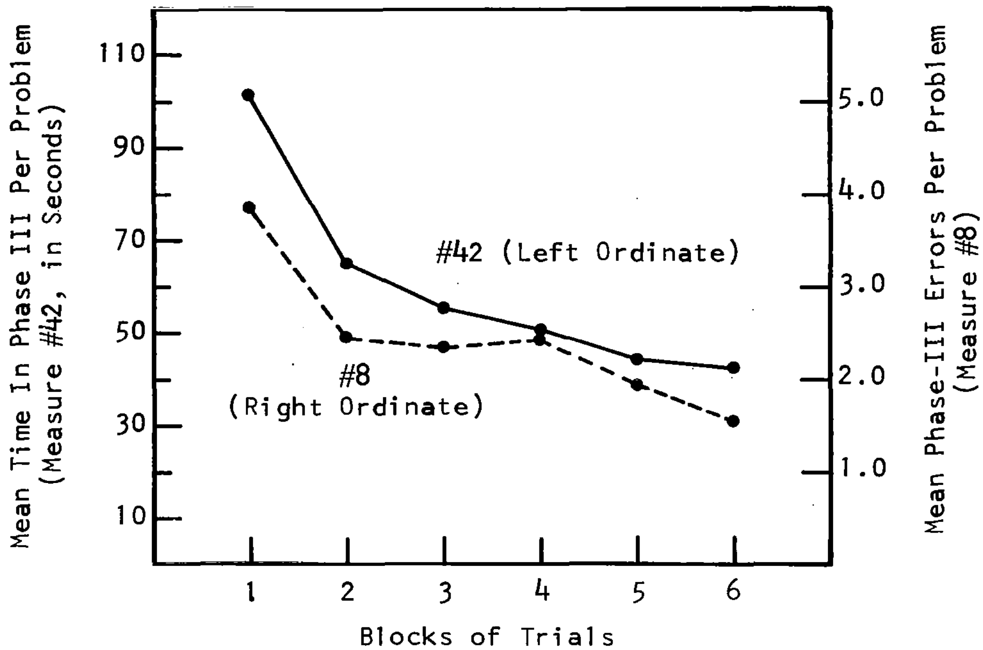

Figure 2. Mean Time in Phase III per Problem (#42) and Mean Phase-III Errors per Problem (#8) as a Function of Blocks of Trials.

Table 12

Odd-Even Reliability Coefficients of Nine Selected Measures that Represent the Five Factors of COTRAN-II Performance (N=84)

Measure Number in COTRAN-II (& COTRAN-I)	Factor Number	Reliability Coefficient: Odd-Even	Reliability Coefficient: Corrected#
25(28)	I	.819**	.901
27(30)	I	.890**	.941
17(17)	II	.851**	.919
1(1)	III	.486**	.654
8(8)	III	.641**	.781
3(3)	IV	.670**	.802
42(65)	IV	.645**	.784
26(29)	V	.796**	.887
33(40)	V	.315*	.479

#Corrected by application of the Spearman-Brown formula.
*$p < .01$; **$p < .0001$

Correlations with Scholastic Aptitude Test.--Because data were available for only 66 of the 84 subjects, the Scholastic Aptitude Test (SAT) scores were not included in the factor analysis of COTRAN-II. Instead, a separate correlational analysis was computed; the results of this analysis are presented in Table 13.

Table 13

Correlations Between Nine Selected Measures that Represent the Five Factors of COTRAN-II Performance and Scholastic Aptitude Test (SAT) Scores (N=66)

Measure Number in COTRAN-II (& COTRAN-I)	Factor Number	Verbal SAT	Quantitative SAT	Total SAT
25(28)	I	.160	.349**	.304*
27(30)	I	.162	.359**	.312*
17(17)	II	.074	.242	.191
1(1)	III	.007	.003	.006
8(8)	III	-.030	-.040	-.041
3(3)	IV	.106	.178	.168
42(65)	IV	-.019	-.128	-.090
26(29)	V	.158	.352**	.305*
33(40)	V	.183	.326**	.303*

*$p < .05$; **$p < .01$.

None of the nine measures that represent COTRAN performance is correlated significantly with the verbal-SAT score, whereas four of the measures (those representing factors I and V) are significantly correlated with the quantitative-SAT score and the total SAT. These results are consistent with the interpretation made previously; namely, that the COTRAN task provides measures not of verbal, but of nonverbal mediation--or that part of intellectual functioning that is represented not by verbal tests of intelligence or intellectual achievement, but by nonverbal tests of such characteristics.

Discussion

The principal goal of the research summarized in the present report has been the development of a performance task to provide measures of intellectual functioning. As discussed in the introduction, the task was to meet certain criteria so that it would be appropriate for use as part of a multiple-task performance (MTP) battery already developed and employed fairly widely as a "synthetic" work situation.

Logical analysis indicated that a problem-solving task would provide the necessary elements of performance desired, but a review of the literature (also discussed in the introduction) failed to uncover a previously designed task that would meet the requirements of the present need. Consequently, a new task had to be created--a task (1) that would make use of the elements of the problem-solving paradigm, (2) that would provide an adequate number of measures to depict an operator's performance accurately, (3) that would provide for sufficient replications during reasonably short intervals of time to permit suitably high reliability of measurement, and (4) a task that would permit the possibility of experimental controls of the important variables associated with its performance. On the basis of the results obtained in the two experiments reported herein, these goals appear to have been reached.

A code-transformation (COTRAN) task based on the "code-lock solving" task of the MTP battery (cf. Alluisi & Fulkerson, 1964; Alluisi et al., 1962) was designed according to a problem-solving paradigm and the apparatus necessary for its use was constructed. In terms of the behavior required of the COTRAN operator, the task may be described as follows:

The operator is required to solve a set of problems. Each problem consists of three phases, each of which must be solved in order to achieve a solution to the over-all problem. The operator's task in phase I is to discover, by use of a systematic search procedure, the correct sequence or order for depressing each of a set of five keys arranged in a keyboard to correspond to the natural placement of the fingertips of the right hand. In phase II, the operator discovers, again by use of a systematic search procedure, a second "correct" sequence for depressing the keys. The task in phase III requires the operator to analyze the two sequences discovered in phases I and II in order to ascertain what transformations of the phase-I sequence must have been made in order to have produced the phase-II sequence. Having identified the necessary transformations, the operator must then apply them to the phase-II sequence in order to generate the final or phase-III sequence that he has to enter into the keyboard.

The first experiment, COTRAN-I, was designed to provide answers to three important questions: (1) How many factors are necessary to an adequate description of COTRAN performance, and what are meaningful identifications of these factors? (2) What measures of performance can be used to represent these factors, and, thereby, to provide direct measures of COTRAN performance in terms of the task's factorial structure? (3) What are the effects on COTRAN performance, as reflected in the selected measures, of the use of (a) different numbers of memory aids and (b) different levels of transformation complexity?

The factor analysis of the 72 measures of performance employed in COTRAN-I resulted in the identification of five factors (see Table 4). These five factors have been identified as (I) general sequences per unit time, (II) general error rate (both of these factors relate to performances in phase I and II of the COTRAN problems), (III) errors in problem solving, (IV) time in problem solving (both of which relate to performances in phase

III of the COTRAN problems), and (V) speed and accuracy in phase II. The last three factors require no further interpretation, but the first-named two do!

Factor I, sequences per unit time in phase I and in phases I and II, may appear at first glance to be a time factor. However, a closer look will show that it is, in reality, a general accuracy factor. That is to say, the principal component of behavior to determine the number of sequences completed in a given period of time of code-lock solving OR phase-I and phase-II COTRAN performance is the number of errors or resets produced. Since each reset requires a return to the beginning of the sequence, the total number of keypresses necessary for a correct solution will vary directly with the number of errors. Thus, even if keypresses are made at a constant rate, the number of sequences completed per unit time will vary as a function of the number of resets encountered or errors produced. As accuracy increases (i.e., as the number of errors or resets decreases), the number of sequences completed per unit time will increase. Thus, factor I should be interpreted as a general accuracy factor.

On the other hand, factor II (which has been identified as an error-rate dimension) is best interpreted as a general response-rate factor. Since the problems and sequences were selected at random for each subject from the full set of 120 possible, and since all subjects were required to use the identical systematic search (keypressing-sequence) procedure, the number of errors produced in ideal performances would be a random variable. With this being the case, then the rate of making errors must be a function of the rate of making keypresses (in the presence of both necessary and erroneous-response-caused resets). Error rate should increase as a function of increases in the over-all rate of responding. Thus, factor II should be interpreted as a general response-rate factor.

The nine measures selected to represent the five factors appear to be appropriate (cf. Table 4). Furthermore, the nine measures appear to be equally well suited to the same five factors obtained in the second experiment (COTRAN-II; cf. Table 9). With use of these measures, the results of several analyses of variance appear to indicate that the problem-solving (factors III and IV) performance obtained with two memory aids is better than that obtained with use of only one memory aid (see Tables 5 and 6), whereas no differences in performance are obtained with use of the three different levels of transformation complexity.

Although the levels of performance obtained with two and with one memory aid are different, there appears to be essentially no other difference in the performances obtained under the two conditions. For example, the factorial structure of COTRAN performance is essentially identical under the two conditions (cf. Tables 2 and 3).

The failure to find a significant effect due to transformation complexity in COTRAN-I might have been a function of the experimental design. That is to say, it might well be that the effects of transformation

complexity will not be highly apparent in the performances of operators who have not yet attained asymptotic levels of performance. It does appear safe to say that the effects, if any, are certainly less than those attributable to the use of one or two memory aids, but it cannot be concluded that transformation complexity has no effect on COTRAN performance.

The second experiment, COTRAN-II, was designed partly to provide a further investigation of the possible effects of the transformation-complexity conditions. Specifically, the experiment aimed to provide answers to four additional questions: (1) What is the factorial structure of the COTRAN task relative to both COTRAN measures and measures obtained from paper-and-pencil tests of intellectual abilities and personality? (2) What are the practice effects, especially for measures of the problem-solving factors? (3) Are the effects of transformation complexities systematic (and statistically significant) when the total number of problems solved by each subject is kept constant? (4) What are the estimated reliabilities of the nine measures selected to represent the five COTRAN factors?

With regard to the first question, the data indicated that the same five COTRAN factors were obtained in the second experiment (see Tables 8 and 9) as had been obtained in the first (see Tables 2 and 4). In fact, the coefficients of correlation between the comparable factors of the two experiments (Tables 4 and 9) were .979, .891, .772, .974, and .883, for factors I through V, respectively. These compare quite favorably with the correlations obtained in COTRAN-I between the different conditions of COTRAN performance (Table 3), as limited by expectations based on the reliability of measurement (Table 12). In short, the five COTRAN factors were the same in the two experiments.

The remaining three of the eight factors identified in COTRAN-II, and the loadings of paper-and-pencil tests on the COTRAN factors, appears to indicate that neither verbal intelligence nor personality characteristics significantly affect COTRAN performance. Rather, the COTRAN task is related to that part of intellectual functioning which is usually referred to as nonverbal mediation. Thus, the Raven test (a nonverbal test of intelligence) and the quantitative SAT scores are correlated with COTRAN performances, whereas the Ohio State Psychological Test (recognized as highly correlated with tests of verbal intelligence) and the verbal SAT scores are not.

Practice effects were clearly indicated in the analyses of variance of the two measures representing the problem-solving factors in COTRAN-II (Table 11 and Figure 2). Also, it is apparent that the subjects did not achieve asymptotic performance in solving the eighteen problems presented. This means that the failure to find a significant effect due to transformation complexity must again be taken as suggestive rather than definitive; the proper definitive test can be made only after subjects have reached asymptote.

The reliabilities of the nine measures selected to represent COTRAN performances are gratifyingly high (see Table 12). By the use of odd-even coefficients, some control was maintained for differential rates of learning on the part of different subjects. Thus, the estimates of reliability reported appear to be free of known sources of bias.

What are the next steps to be taken? Since the purpose behind the development of the COTRAN task is related to its use in an MTP battery, the next steps appear to require investigation of the ways in which the two can be combined. For example, because the tests in the MTP battery can be presented in different combinations, different work loads are imposed on the operator. The effects of adding the COTRAN task to the multiple-task performance situation must be assessed, both with regard to its effect on the other tasks and to the effect of the combination with other tasks on COTRAN performance and structure. Planning for this research, and for research to indicate the practice parameters of COTRAN performance is now underway.

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